Characterization and Modeling of Archipelago Strait Dynamics

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LONG-TERM GOALS

The goal of this project is to meet future Navy environmental forecasting requirements through a better understanding of the importance of atmospheric forcing mechanisms on the ocean and scales to numerical model resolution in coastal and other complex geometry regions.

OBJECTIVES

The objectives of this project are to evaluate high-resolution atmospheric numerical modeling skill through real-time forecast support of research cruise operations and ocean modeling experiments over the Philippine archipelago, and to investigate the sensitivity of atmospheric and ocean model forecasts to horizontal model resolution in the straits and coastal regions of this complex archipelago, using both one-way and two-way coupling between the ocean and atmosphere.

APPROACH

Accurate ocean prediction in coastal regions, such as the Philippine archipelago, depends on atmospheric forcing with sufficient resolution to represent complex flow through the straits, around islands, and in coastal boundary regions. Our approach is to use the existing atmospheric and ocean data assimilation and modeling infrastructure of the Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS®[1]) to provide high-resolution atmospheric fields to support ocean modeling research over the Philippine archipelago. COAMPS has four major components: the NRL Atmospheric Variational Data Assimilation System (NAVDAS) for atmospheric analyses; the NRL Coupled Ocean Data Assimilation System (NCODA) system for ocean analyses; the NRL nested, non-hydrostatic atmospheric model; and the NRL Coastal Ocean Model (NCOM). Two-way atmosphere-ocean coupling is available using the Earth Systems Modeling Framework (ESMF) to provide communication between the atmosphere (COAMPS) and ocean (NCOM). Within this framework the models have been run in both real-time and hindcast (reanalysis) modes for time periods that include the Philippines Experiment (PhilEX) field experiment and at resolutions from 27 km to 3 km in the atmosphere, and 9 km to 1 km in the ocean.

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The key participants for this program include the principal investigator, Dr. James Doyle, and Dr. Paul May of Computer Sciences Corporation (CSC). We are also working closely with Dr. Julie Pullen of Steven Institute as well the PhilEX team.

WORK COMPLETED

1. *Real-time forecasting for Regional Intensive Observing Period 2009 (RIOP09).*

During a six-week period encompassing the IOP09 field experiments, NRL provided real-time forecasting support (ocean and atmosphere) and regular email updates to the PhilEX chief scientist using COAMPS-OS®[1] configured for the Philippines region. Previously, during the latter half of RIOP08, we also supplied interpretation of the modeling results onboard a research cruise vessel. Forecasts typically extended to 48 hours with 9 km atmosphere and ocean model resolution.

2. *Hindcast high-resolution coupled atmosphere-ocean simulations of RIOP08.*

To carry out further analysis and make comparisons with *in situ* data, high-resolution hindcast ocean simulations of the winter 2008 cruise period were completed, with and without tides. These hindcasts are compared to underway Acoustic Doppler Current Profiler (ADCP) data, moored ADCP data, moored profiler data, and Conductivity, Temperature, Depth (CTD) data. The COAMPS-ESMF two-way coupled system ran in one- and two-way coupled modes with 27-, 9-, and 3-km resolution domains, with embedded 3- and 1-km coupled ocean model computational grids with 40 vertical layers. Atmospheric fluxes and ocean sea-surface temperatures are exchanged between the two models at 12-minute simulation intervals. The simulation covers January and February of 2008, the time period of the PhilEX RIOP08 research cruise.

RESULTS

1. *Real-time forecasting for RIOP09.*

Mean surface winds from COAMPS forecasts during IOP09 (Fig. 1) show less intense winter monsoon wind forcing than was seen during IOP08. As a consequence of the mild or nonexistent northeasterly monsoon, weather patterns during the IOP09 cruise appear to be influenced more by the easterly trade winds. Mean ocean surface currents during the two observations periods suggest a stronger Mindanao current and accompanying Mindanao eddy during IOP09 and the potential for stronger flow through the Surigao Strait.

2. *Hindcast high-resolution coupled ocean simulation of RIOP08.*

Modeled temperature and salinity bias and root-mean-squared error (RMSE) statistics for the ocean simulations are calculated using IOP08 CTD data (Arnold Gordon) as a reference. These statistics show that the model, without data assimilation, is typically too cold (Fig. 2) and too salty in the surface layer (<100m). Much of the model temperature bias below 200 m is due to a +3°C temperature anomaly that appears in five of the CTD casts from the so-called “mixing bowl” at the confluence of the

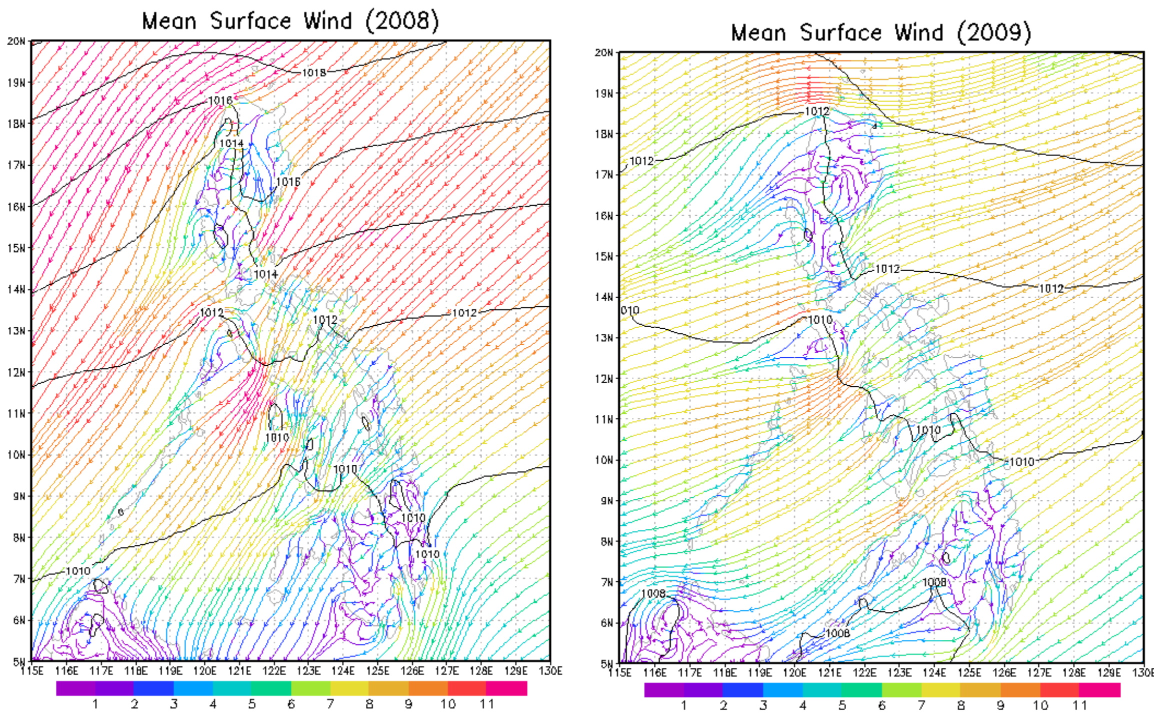

Figure 1. Mean COAMPS forecast surface winds (m s^{-1}) for IOP '08 and '09.

Mindoro, Tablas and Panay Straits. Those CTD casts may include the signature of large internal tides known to be common to the area. When CTD stations with warm temperature anomalies at 300 m are removed, the temperature biases below 100 m are significantly reduced (dashed lines in Fig. 2).

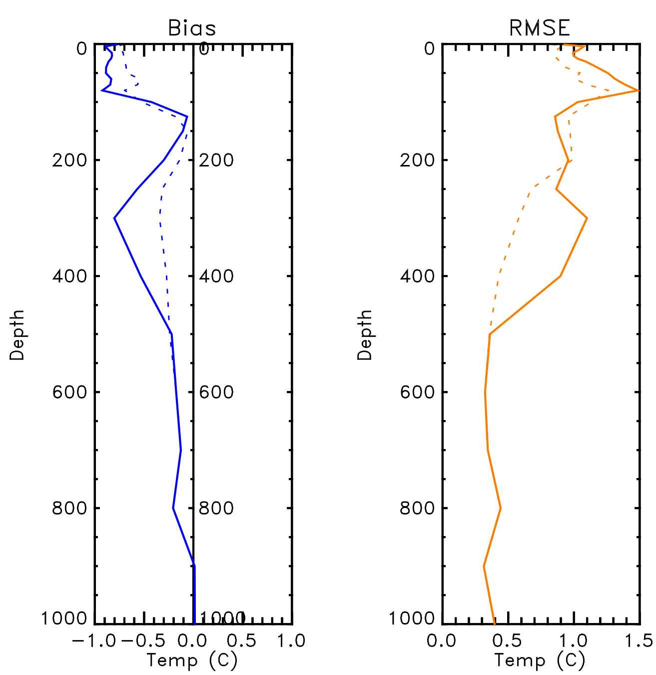

Figure 2. Model Temperature Bias and RMSE for IOP08.

A very high resolution coupled model (1-km resolution ocean model forced by a 3-km resolution atmosphere model) shows highly variable flow through the Mindoro and Tablas Straits. A snapshot of the streamlines (Fig. 3) gives some indication of the complex eddy shedding and side-wall boundary layers that are modeled in the "mixing bowl".

To determine if these flows are forced by local wind stress and sea-level differences between interior seas of the Philippine Archipelago, we calculated the principle components of variability for transports through the Mindoro, Tablas, and Verde Island Passages; sea-levels in the South China, Sulu, Tayabas and Sibuyan Seas; and wind stress over Tayabas Bay. The first three empirical orthogonal modes for these parameters (Fig. 4-6) indicate that about 50% of the variability is from sea-level in the four basins rising and falling in unison. The second mode, with 23% of the variability, is due to externally forced flows through the three straits and adjustments required by continuity. The third mode, with only 17% of the variability, is due to direct forcing of flow through the Tablas Strait and Verde Island Passage flow by wind stress over Tayabas Bay.

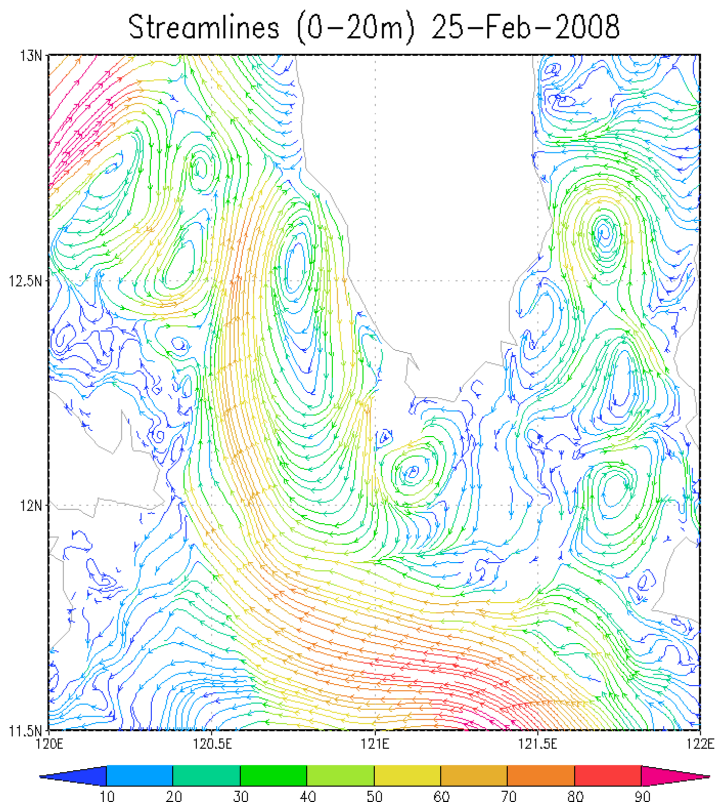

Figure 3. Surface streamlines showing the confluence of Mindoro, Tablas, and Panay Straits.

IMPACT/APPLICATIONS

An improved representation of the atmosphere and ocean is critical for the Navy's control of the sea and air. Air and missile defense, undersea warfare, and special operations all depend on the ability to predict the state of weather and seas at high resolution over the battle space. Accurate predictions of the atmosphere and ocean require high-resolution models that include the complex physics of each flu-

id and that represent the coupling of the two systems properly. The characterization of the coupled atmosphere-ocean environment must be done through an integrated system that relies on data assimilation and numerical modeling for both the atmosphere and the ocean. This research seeks to identify the advantages of high-resolution in regions of complex island geometry and gain insight into coupled modeling issues using one-way and two-way interactive approaches in these challenging regions. A knowledge of environmental conditions will aid warfighters in crafting strategy and allow the Navy to operate with more flexibility.

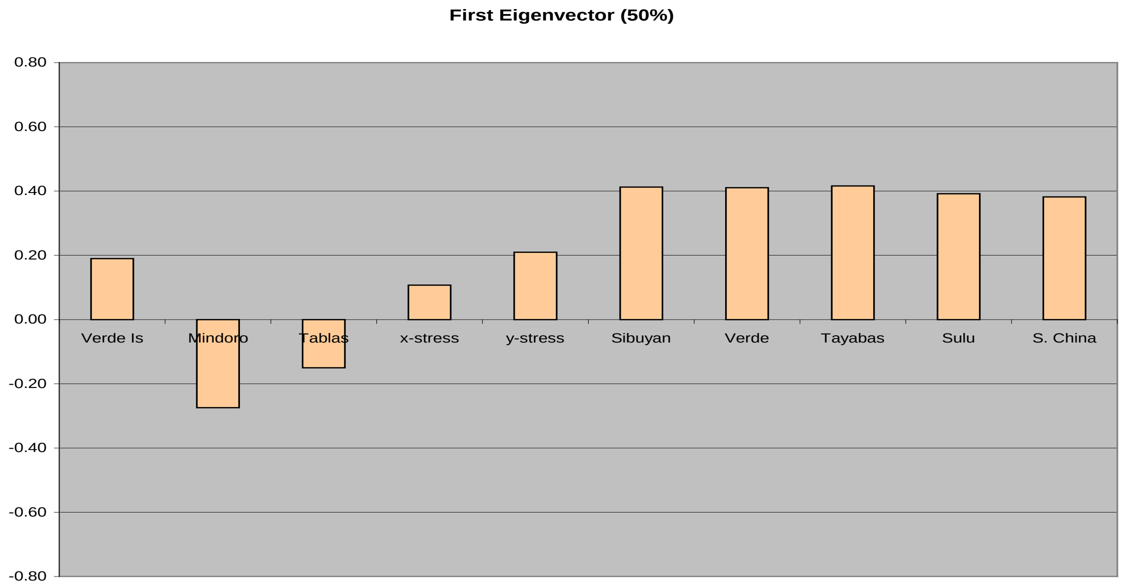

Figure 4. First principle component of strait transport, wind stress, and sea-level.

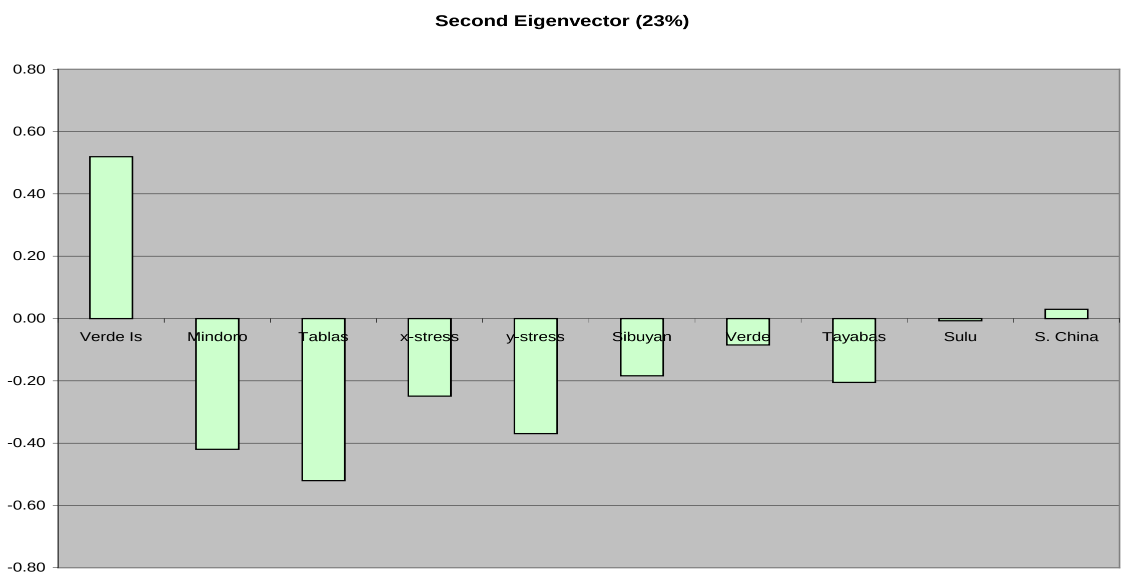

Figure 5. Second principle component of strait transport, wind stress, and sea-level.

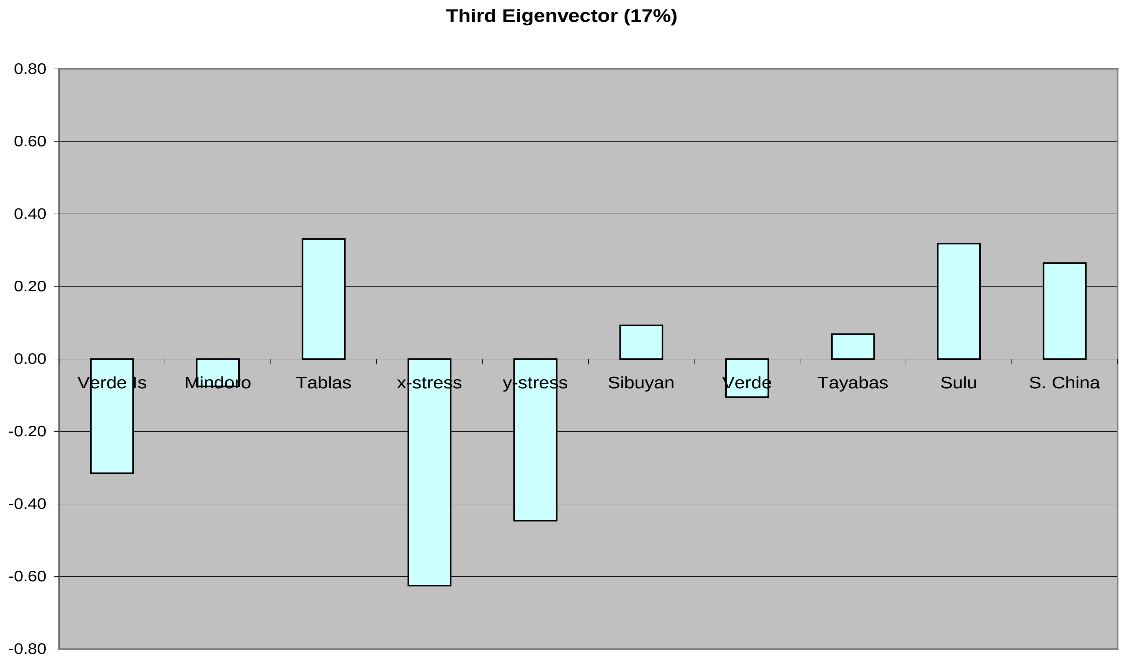

Figure 6. Third principle component of strait transport, wind stress, and sea-level.

TRANSITIONS

The coupled COAMPS system will transition to 6.4 projects within PE 0603207N (SPAWAR, PMW-120) that focus on the transition of COAMPS to Fleet Numerical Meteorology and Oceanography Center.

RELATED PROJECTS

COAMPS will be used in related 6.1 projects within PE 0601153N that include studies of air-ocean coupling, boundary layer studies, and topographic flows and in related 6.2 projects within PE 0602435N that focus on the development of the atmospheric components (data quality control, data analysis/assimilation, model initialization, and forecast model) of COAMPS.